

HIGGS FIELDS IN SUPERSYMMETRICAL THEORY

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Abstract

The theory including interaction between Siegel and gauge multiplets leads to the model of nonbreaking supersymmetry which contains massive scalar, fourcomponent fermion and gauge fields. The upper bound of Higgs boson mass is estimated as heaviest fermion mass. The idea to replace Higgs field by scalar superpartner or by auxiliary fields of corresponding supermultiplet is discussed.

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Realistic supersymmetry model has to contain a mechanism for the breakdown of supersymmetry that splits masses of the different members of supermultiplets and in addition induces the scale of the weak interaction breakdown. One more reason why supersymmetry is of considerable interest is that one could solve in principle Higgs bosons problem. It is well-known that standard model is not the final theory of the world since it contains some twenty free parameters. There is especially one sector in the theory, Higgs sector, which remains rather mysterious. But well-known breaking mechanisms [1, 2, 3] say us nothing about standard model action for a massive gauge field because any term coupling matter fields and gauge fields is absent in their superpotentials of interaction. It is enough difficult to mix auxiliary and physical components thereby to break supersymmetry.

Matter fields are considered to be described by Wess-Zumino supermultiplet G just as gauge field is included in vector multiplet V [4]. W. Siegel [5] has suggested a term of interaction between both V and G multiplets mentioned above:

$$S_{int} = \int d^4x d^4\theta GV \sim \int d^4x d^2\theta \psi_\alpha W^\alpha + h.c. \quad (1)$$

Here ψ_α is Siegel chiral spinor superfield [5] and $W_\alpha = \bar{D}^2 D_\alpha V$ is field strength of abelian vector multiplet V . Such an action describes a massive vector multiplet by gauge invariant term $(\psi_\alpha W^\alpha)$.

On the other hand, Siegel multiplet can be written as linear multiplet (C, χ, v_μ) which is also alternative description of field content that are contained in Wess-Zumino model [4]. This multiplet ψ may be generated from scalar supermultiplet ϕ by putting the following coupling

$$\mathcal{D}^A \mathcal{D}_A \phi = 0, \quad (2)$$

and in fourcomponent notations the transformation laws are

$$\delta C = i\bar{\varepsilon}\gamma_5\chi, \quad \delta\chi = (-i\gamma_5\hat{\partial}C + \hat{A})\varepsilon, \quad \delta A_\mu = -\bar{\varepsilon}\sigma_{\mu\nu}\partial^\nu\chi. \quad (3)$$

Using the rules of supertensor calculus from West textbook [4], the action (1) may be rewritten via component fields of G and of V as

$$S_{int} = \int d^4x [GV]_D = \int d^4x (CD - v_\mu A^\mu - \bar{\lambda}\chi), \quad (4)$$

where $V = (A_\mu, \lambda, D)$.

It should be noted that the role of Bose components of G is reversed: the scalar C is now physical (instead of auxiliary D), and the transverse vector v_μ has got one physical and two auxiliary components (instead of two physical and one auxiliary ones for A_μ), i. e. in action (4) physical fields and auxiliary fields are mixed in nontrivial way. If supersymmetry

are broken then auxiliary fields including of v_μ -components get their nonvanishing vacuum expectation values. Second term of action (4) helps to rise a question: could we use them to clear up Higgs boson role in standard model?

Gremmer and Scherk [6] tried earlier to understand how the spontaneous symmetry breakdown can be generated without introducing the scalar Higgs field with help of fully massless theories. However, all calculations in papers [5, 6] are carried out with abelian Lagrangian but for construction of standard model more wide class of symmetries is used. Therefore an attempt is made to generalize a mechanism from Gremmer's and Scherk's article on non-abelian multiplets.

Let us consider the Siegel multiplet ψ_α which are transformed under non-abelian gauge group:

$$\psi_\alpha^a \rightarrow \psi_\alpha'^a = (e^\Lambda)^a_b \psi^b, \quad (5)$$

where $\Lambda^a_b = \Lambda^i(T_i)^a_b$ and $(T_i)^a_b$ are generators of gauge group. The transformation laws for ψ'^α fields copy directly the Eq.(3) with replacing the derivative on a covariant one.

This fields are coupled to Yang-Mills supermultiplet V^a which supersymmetric and gauge transformations have standard expansion [5].

Corresponding action is the following sum:

$$S = S_{YM} + S_{Sie} + S_{int}. \quad (6)$$

Here S_{YM} describes Yang-Mills supermultiplet

$$S_{YM} = \int d^4x \, Tr \left\{ -\frac{1}{4} F_{\mu\nu}^a F^{a\mu\nu} - \frac{1}{2} \bar{\lambda}^a \hat{D} \lambda^a + \frac{1}{2} (D^a)^2 \right\}, \quad (7)$$

S_{Sie} is an action of Siegel superfield [4]

$$S_{Sie} = \int d^4x [G^a G^a]_D = \int d^4x \, Tr \left\{ -\frac{1}{2} (D_\mu C^a)^2 - \frac{1}{2} \bar{\chi}^a \hat{D} \chi^a - \frac{1}{2} (v^a)_\mu^2 \right\}, \quad (8)$$

and S_{int} is a term of the interaction

$$S_{int} = \frac{k}{2} \int d^4x [G^a V^a]_D = \frac{k}{2} \int d^4x \, Tr \left\{ C^a D^a - A_\mu^a v^{a\mu} - \bar{\lambda}^a \chi^a \right\}. \quad (9)$$

The boson part of new Lagrangian

$$\mathcal{L}_b = -\frac{1}{4} F_{\mu\nu}^a F^{a\mu\nu} + \frac{1}{2} (D^a)^2 - \frac{1}{2} (D_\mu C^a)^2 - \frac{1}{2} (v_\mu^a)^2 + \frac{k}{2} C^a D^a - \frac{k}{2} A_\mu^a v^{a\mu}, \quad (10)$$

and the fermion part

$$L_f = -\frac{1}{2} \bar{\lambda}^a \hat{D} \lambda^a - \frac{1}{2} \bar{\chi}^a \hat{D} \chi^a - \frac{k}{2} \bar{\lambda}^a \chi^a \quad (11)$$

invariant under non-abelian group of the internal symmetry.

We can now diagonalize the Lagrangian (9) by rewriting it in terms of new fields, as it has made in Gremmer's and Scherk's paper [6],

$$h_\mu^a = v_\mu^a + \frac{k}{2}A_\mu^a, \quad E^a = D^a + \frac{k}{2}C^a, \quad (12)$$

$$\mathcal{L}_b = -\frac{1}{4}F_{\mu\nu}^a F^{a\mu\nu} + \frac{k^2}{8}(A_\mu^a)^2 - \frac{1}{2}(D_\mu C^a)^2 - \frac{k^2}{8}(C^a)^2 - (h_\mu^a)^2 + (E^a)^2. \quad (13)$$

However one must be careful, because v_μ has one physical degree of freedom and two auxiliary degrees of freedom and is constrained by the condition $D^\mu v_\mu^a = 0$. Therefore a new scalar field B^a and ortonormal basis of vectors e_A should be introduced where $v_\mu^a = D_\mu B^a +$ two additional terms $e_E^\mu E^a, e_F^\mu F^a$ for off-shell Lagrangian so that

$$(v_\mu^a)^2 = (D_\mu B^a)^2 + (E^a)^2 + (F^a)^2, \quad (14)$$

where E^a and F^a are scalar and pseudoscalar auxiliary fields respectively.

It should be noted that Gremmer's and Scherk's conditions $E^a = 0, h_\mu^a = 0$ find now a physical sense: these are the equations for auxiliary fields. It is nontrivial that in final expressions of equations

$$E^a = -\frac{k}{2}e_E^\mu A_\mu^a; \quad F^a = -\frac{k}{2}e_F^\mu A_\mu^a; \quad D^a = -\frac{k}{2}C^a, \quad (15)$$

the nonzero spin fields are included.

Let us return to fermion sector and examine the particle spectrum more closely. It is important to note that Majorana fermions cannot carry any conserved additive quantum number. The charged fermions is described by four-component Dirac spinors therefore two Majorana states λ^a, χ^a should be mixed so that they lead to new massive fields. Such a model suggested by Wolfenstein [7] is used often for a description of the neutrino oscillation. This choice is known to correspond a very general massive term of the four-component fermion field [8]. It is convenient to choose new spinors η, ω obtained after rotation in a plane $O(\lambda, \chi)$. Here

$$\eta = \lambda \cos \theta - \chi \sin \theta = \psi_L + \psi_L^c, \quad (16)$$

$$\omega = \lambda \sin \theta + \chi \cos \theta = \psi_R + \psi_R^c \quad (17)$$

are self-conjugative fields with respect to charge-conjugation operator C . The new mass term [8] is equivalent to

$$L_{fm} = \frac{k}{2}(\bar{\eta}\omega \cos^2 \theta + \bar{\omega}\eta \sin^2 \theta) + \frac{k}{4}(\bar{\eta}\eta + \bar{\omega}\omega) \sin 2\theta. \quad (18)$$

It means that fermion sector ψ^a of standard model including neutrinos ν_l and charged leptons l may be wholly described with help of such a set and of the transformations of the internal symmetry group, i.e.

$$L_{fm} = \frac{k}{2} \bar{\psi}^a \psi^a + A \bar{\psi}_L^{ac} \psi_L^a + B \bar{\psi}_R^{ac} \psi_R^a, \quad (19)$$

where ψ^a is the fields implemented the representation of symmetry group, for example, $\psi^a = (e_L, \nu_e)$. Left or right components of ψ could be included in supermultiplets G or V correspondingly.

Thus, our model of nonbreaking supersymmetry contains massive scalar field D^a , fermion family ψ^a and gauge field A_μ^a transformed under internal symmetry group. Here, v_μ^a is simply the Goldstone bosons which are eaten by gauge fields A_μ^a thereby giving mass to the supermultiplet members.

The question remains now whether the breakdown of internal symmetry can be related to the breakdown of supersymmetry. The first of the possible scenarios is that to break internal symmetry at low energy. Then, the vacuum expectation values of all auxiliary fields vanish

$$\langle E^a \rangle = \langle F^a \rangle = \langle D^a \rangle = 0 \quad (20)$$

and the supersymmetry is unbroken. This model contains only scalar C^a from new (non-detected) particles and dynamical term $\frac{1}{2}(D_\mu C^a)^2$ in Lagrangian (13) allows to choose it on a role of Higgs field to provide standard model with soft breakdown of the internal symmetry.

It should be noted the absent of Yukawa terms generating the fermion masses. These masses as well as Higgs boson mass are determined by Siegel interaction, see Eqs.(13,18). For construction of reach picture of fermion and of boson sectors the transformations of the internal symmetry have to be engaged in addition to mixed mechanism mentioned above. An upper bound of Higgs mass is determined now by mass $\frac{k}{2}$ of Dirac fermion in Eq.(19), the value of this mass is probably a few *GEV*.

Besides, present theory prompts us to consider the production of gauge bosons as supersymmetrical transition inside of Yang–Mills multiplet V^a ($\lambda^a \rightarrow A_\mu^a$). Therefore, Higgs field presented by scalar C^a could be an superpartner of right-handed component of Dirac state.

Here $L - R$ symmetry is conserved and Dirac field ψ_a can carry additive quantum number, e.g. electric charge. For neutrino Majorana mass term violates only lepton family number.

Consequently, the Higgs does not couple directly to left-handed components of quarks and leptons and its production and detection in experiment remains difficult problem. An

exception is production in the decay of Z boson, *i.e.* $e^-e^+ \rightarrow Z^* \rightarrow ZH$ process.

Another possibility of theory construction is opened when masses of superpartners $\frac{k}{2}$ coincide with mass of gauge bosons W^\pm, Z . Then the idea to replace Higgs fields by corresponding auxiliary fields E^a, F^a, D^a of G and V supermultiplets may be applied. Indeed Lagrangian of standard model after symmetry breaking contains both nonvanishing vacuum expectation value of Higgs field and physical component or so-called Higgs boson. In order to obtain on-shell supersymmetric Lagrangian we have only to change auxiliary fields E^a, F^a, D^a on their vacuum expectation values $\langle E^a \rangle, \langle F^a \rangle, \langle D^a \rangle$. If auxiliary fields is chosen on role of Higgs fields then after supersymmetry breaking corresponding Lagrangian does not include any additional physical state in comparison with initial off-shell Lagrangian. As former, transformation of internal symmetry has to take a part in construction of final theory.

Besides, the realistic model must contain a mechanism for the breakdown of supersymmetry that splits the masses of different members of the supermultiplet and in addition induces the scale of the breakdown of internal symmetry. Up to now there is no model [9] which is theoretically completely satisfactory in this respect. It seems however that these questions can be now answered at energy scales less then $M_W \sim 100 \text{ GeV}$ and it is necessary to investigate right-handed sector of supersymmetrical models.

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